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Preface

The United States Environmental Protection Agency (EPA) prepares the official *U.S. Inventory of Greenhouse Gas Emissions and Sinks* to comply with existing commitments under the United Nations Framework Convention on Climate Change (UNFCCC).[1] Under a decision of the UNFCCC Conference of the Parties, national inventories for most UNFCCC Annex I parties should be provided to the UNFCCC Secretariat each year by April 15.

In an effort to engage the public and researchers across the country, the EPA has instituted an annual public review and comment process for this document. The availability of the draft document is announced via Federal Register Notice and is posted on the EPA web page.[2] Copies are also mailed upon request. The public comment period is generally limited to 30 days; however, comments received after the closure of the public comment period are accepted and considered for the next edition of this annual report. The EPA's policy is to allow at least 60 days for public review and comment when proposing new regulations or documents supporting regulatory development—unless statutory or judicial deadlines make a shorter time necessary—and 30 days for non-regulatory documents of an informational nature such as the Inventory document.

[1] See http://www.unfccc.de

[2] See http://www.epa.gov/globalwarming/emissions/national

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Changes in This Year's Inventory Report

Each year the EPA not only recalculates and revises the emission and sink estimates for all years that are presented in the *Inventory of U.S. Greenhouse Gas Emissions and Sinks* but also attempts to improve the analyses themselves through the use of better methods or data as well as the overall usefulness of the report. A summary of this year's changes is presented in the following sections and includes updates to historical data in addition to changes in methodology. The magnitude of each change is also described. Table Changes-1 summarizes the quantitative effect of these changes on U.S. greenhouse gas emissions and Table Changes-2 summarizes the quantitative effect on U.S. sinks, both relative to the previously published U.S. Inventory (i.e., 1990-1998 report). These tables present the magnitude of these changes in units of teragrams of carbon dioxide (CO_2) equivalents (Tg CO_2 Eq.). (See Box Changes-1.)

Changes in historical data are generally the result of changes in statistical data supplied by other agencies. Data sources are provided for further reference.

For methodological changes, differences between the previous Inventory report and this report are explained. In general, when methodological changes have been implemented, the entire time series (i.e., 1990 through 1998) has been recalculated to reflect the change.

Box Changes - 1: Emission Reporting Nomenclature

The Global Warming Potential (GWP) weighted emissions of all direct greenhouse gases in this report are presented in terms of equivalent emissions of carbon dioxide (CO_2), using units of teragrams of carbon dioxide equivalents (Tg CO_2 Eq.). In previous year's inventories emissions were reported in terms of carbon—versus carbon dioxide—equivalent emissions, using units of million metric tons of carbon equivalents (MMTCE). This change of units for reporting was implemented so that the U.S. Inventory would be more consistent with international practices, which are to report emissions in carbon dioxide equivalent units.

In order to convert the emission estimates presented in this report to those provided previously, the following equation can be employed:

Tg CO_2 Eq. = MMTCE $\times$ ($^{44}/_{12}$)

There are two elements to the conversion. The first element is simply nomenclature, since one teragram is equal to one million metric ton:

Tg = 10^9 kg = 10^6 metric tons = megaton = 1 million metric tons

The second element is the conversion, by weight, from carbon to carbon dioxide. The molecular weight of carbon is 12, and the molecular weight of oxygen is 16; therefore, the molecular weight of CO_2 is 44 (i.e., 12+[16$\times$2]), as compared to 12 for carbon alone. Thus, carbon comprises 12/44^{ths} of carbon dioxide by weight.

Table Changes -1: Revisions to U.S. Greenhouse Gas Emissions (Tg CO_2 Eq.)

Gas/Source	1990	1991	1992	1993	1994	1995	1996	1997	1998
CO_2	**(1.4)**	**(1.1)**	**9.4**	**0.7**	**18.0**	**26.0**	**27.1**	**28.7**	**11.7**
Waste Combustion	7.2	8.3	8.9	9.7	10.7	12.0	12.5	13.1	12.3
Fossil Fuel Combustion	(4.8)	(5.5)	4.2	(5.4)	11.2	17.4	18.1	19.0	3.3
Natural Gas Flaring	(4.0)	(4.0)	(3.9)	(3.7)	(3.6)	(3.6)	(3.5)	(3.5)	(3.4)
Other[a]	0.1	0.1	0.1	0.1	(0.2)	0.2	0.1	+	(0.5)
CH_4	**(7.7)**	**(8.7)**	**(9.4)**	**(17.1)**	**(19.5)**	**(24.6)**	**(33.5)**	**(41.7)**	**(38.6)**
Manure Management	(28.5)	(29.4)	(31.0)	(34.7)	(38.6)	(41.4)	(44.2)	(48.5)	(48.6)
Wastewater Treatment	8.0	8.1	8.2	8.3	8.4	8.5	8.5	8.6	8.7
Enteric Fermentation	9.5	8.6	10.2	6.0	9.1	8.3	5.5	4.2	3.9
Landfills	3.7	4.3	3.5	3.9	3.3	1.0	(1.5)	(2.9)	(2.0)
Other[a]	(0.4)	(0.4)	(0.4)	(0.6)	(1.8)	(1.2)	(1.8)	(3.2)	(0.7)
N_2O	**+**	**(0.8)**	**0.1**	**(1.3)**	**(2.4)**	**(3.8)**	**(4.0)**	**(4.8)**	**(4.0)**
Manure Management	3.7	3.5	3.4	3.3	3.0	2.7	2.8	2.8	2.5
Mobile Sources	3.9	4.1	4.2	4.1	3.6	2.9	1.2	1.8	1.2
Agricultural Soil Management	(7.2)	(8.1)	(7.1)	(8.3)	(8.7)	(9.6)	(7.6)	(9.0)	(7.2)
Other[a]	(0.4)	(0.4)	(0.4)	(0.4)	(0.3)	0.2	(0.4)	(0.3)	(0.5)
HFCs, PFCs, and SF_6	**(1.5)**	**(1.8)**	**(2.7)**	**(3.6)**	**(5.1)**	**(7.3)**	**(7.8)**	**(6.3)**	**(9.2)**
Magnesium Production and Processing	(0.7)	(1.7)	(2.6)	(3.7)	(4.9)	(5.5)	(5.4)	(3.5)	(4.7)
Substitution of Ozone Depleting Substances	NC	NC	NC	NC	(0.1)	(1.6)	(2.4)	(2.9)	(3.5)
Other[a]	(0.8)	(0.1)	(0.1)	0.1	(0.1)	(0.3)	+	0.1	(1.0)
Net Change in Total Emissions[b]	**(10.6)**	**(12.5)**	**(2.6)**	**(21.3)**	**(8.9)**	**(9.7)**	**(18.2)**	**(24.2)**	**(40.2)**
Percent Change	**-0.2%**	**-0.2%**	**+%**	**-0.3%**	**-0.1%**	**-0.2%**	**-0.3%**	**-0.4%**	**-0.6%**

+ Does not exceed 0.05 Tg CO_2 Eq.
[a] Includes other source categories with only minor or no versions made to emission estimates.
[b] Excludes emissions from international bunker fuels and carbon sinks.
NC (No Change)
Note: Totals may not sum due to independent rounding.

Changes in Historical Data

- In the CO_2 Emissions from Fossil Fuel Combustion section of the Energy chapter, energy consumption data have been updated by the Energy Information Administration (EIA 2000a, 2000b, 2000c) for selected years (see below for detail on methodological changes). For example, the amount of coal combusted in the industrial end-use sector by nonutility generators of electricity was reused upward, resulting in an average 31.1 Tg CO_2 Eq. increase in emissions. In addition, the carbon content coefficients for motor gasoline blend components, unfinished oils, and miscellaneous petroleum products were revised from static to annually variable coefficients, based on EIA (2000b). The annually variable carbon content coefficients for coal (i.e., residential, commercial, industrial coking, industrial other, and utility coal) were expanded to include more significant digits, also based on EIA (2000b). These data changes, combined with the methodological changes described below, resulted in an average increase of 6.4 Tg of CO_2 Eq. (0.1 percent) in annual CO_2 emissions from fossil fuel combustion for 1990 through 1998.
- In the Stationary Combustion (excluding CO_2) section of the Energy chapter, two revisions to the energy consumption data were made. First, the EIA has provided estimates for commercial wood energy consumption for 1990 through 1992, which were previously not provided, and has revised the wood energy consumption data for the remaining years. Second, wood biomass has been reported separately

Table Changes-2: Revisions to Net CO_2 Sequestration from Land-Use Change and Forestry (Tg CO_2 Eq.)

Component	1990	1991	1992	1993	1994	1995	1996	1997	1998
Forests	140.5	152.6	204.3	(174.3)	(180.9)	(173.6)	(178.0)	(138.8)	(132.5)
Agricultural Soils	(40.4)	(39.7)	(40.9)	(70.0)	(69.3)	(68.8)	(68.9)	(69.0)	(77.3)
Landfilled Yard Trimmings	NC	NC	NC	NC	NC	NC	NC	NC	(0.5)
Total Change in Land-Use Change and Forestry Sequestration	**100.1**	**112.9**	**163.4**	**(244.3)**	**(250.2)**	**(242.4)**	**(246.9)**	**(207.8)**	**(210.3)**
Percent Change	**-8.6%**	**-11.2%**	**-15.6%**	**29.4%**	**30.4%**	**31.2%**	**31.9%**	**26.8%**	**27.2%**

NC (No Change)
Note: Numbers in parentheses indicate an *increase* in estimated net sequestration, or a decrease in net flux of CO_2 to the atmosphere. In the "percent change" row, negative numbers indicate that the sequestration estimate has decreased, and positive numbers indicate that the sequestration estimate has increased. These percents are based on sequestration estimates that were rounded to the nearest 10^2 gigagram CO_2. The previously published U.S. Inventory did not include agricultural soils in the total flux estimates for land-use change and forestry, so the data in the "agricultural soils" row are equal to the agricultural soil sequestration estimates presented in this Inventory. Totals may not sum due to independent rounding.

from wood wastes, liquors, municipal solid waste, tires, etc., in EIA's estimates of consumption for fuel combustion (EIA 2000a). Only estimates of wood consumption were used to calculate non-CO_2 emissions from stationary combustion. These revisions resulted in average decrease of 0.2 Tg CO_2 Eq. (2.8 percent) in annual stationary combustion methane emissions for 1990 through 1998. The average decrease in N_2O emissions was 0.4 Tg CO_2 Eq. (2.9 percent) for 1990 through 1998.

- In the Mobile Combustion (excluding CO_2) section of the Energy Chapter, estimates of 1996 to 1998 vehicle miles traveled were revised by the Federal Highway Administration (FHWA 1999). This data change, combined with the methodological changes described below, resulted in an average decrease of 0.4 Tg CO_2 Eq. (7.1 percent) in annual methane emissions for 1990 through 1998. Average N_2O emissions increased by 3.0 Tg CO_2 Eq. (5.2 percent) annually for 1990 through 1998.
- In the Coal Mining section of the Energy chapter, data on underground emissions have been revised and State gas sales data and coal production totals have been updated by DOE's Energy Information Administration (EIA 2000e). Due to improvements in the data, this year's inventory includes 5 additional coal mines for the 1998 data. Each year, States provide gas sales data, which are used to estimate emissions avoided from gas recovery projects. Previously, gas sales data for 1998 were not available, but this inventory reflects the final data from the States. Finally, DOE's EIA reports surface and underground production in the Coal Industry Annual (EIA 1999a). Although total production was available for 1998, the apportionment to surface and underground mining was not available. The total coal production values remain unchanged. These revisions result in an annual increase in CH_4 emissions of 1.3 Tg CO_2 Eq. (2.0 percent) for 1998.
- In the Natural Gas Systems section of the Energy chapter, methane emission estimates have been revised to incorporate new activity driver data on gas wells for 1997 and 1998 (AGA 1998, 1999a, 1999b, 2000, IPAA 1999). These data changes, combined with the methodological changes described below, resulted in an average decrease of 0.6 Tg CO_2 Eq. (0.5 percent) in annual methane emissions from natural gas systems from 1990 through 1998.
- In the Natural Gas Flaring and Criteria Pollutant Emissions in the Oil and Gas Activities section of the Energy chapter, a conversion factor accounting for the vented gas from petroleum systems has been corrected from previous reports. The amount of natural gas flared is calculated by subtracting the vented gas emissions from the total gas reported by EIA as combined vented and flared gas (EIA 2000d). Previ-

ously, the conversion value for vented gas was miscalculated, causing the amount of gas vented to appear negligible. Correction of the conversion factor caused the estimate of natural gas vented to increase to between 20 and 40 percent of the total gas vented and flared. This caused an associated average decrease in annual CO_2 emissions from natural gas flaring of 3.7 Tg CO_2 Eq. (29 percent) from 1990 through 1998. The EPA (2000b) has also revised estimates for criteria pollutants from oil and gas activities for 1990 through 1998. These revisions resulted in average increases of 3.5 percent in annual NO_x emissions, and 3.1 percent in annual CO emissions, and an average annual decrease of 0.1 percent in NMVOC emissions from 1990 through 1998.

- In the International Bunker Fuels section of the Energy chapter, civil marine bunker fuel data for 1990 were revised with previously unavailable data provided by DOC (2000). In addition, activity data for foreign airlines at U.S. airports in 1998 have been adjusted (BEA 2000). Lastly, DESC (2000) revised their estimates of jet fuel and aviation gasoline consumption by the military for international bunkers for 1990 to 1994. These revisions resulted in a decrease in CO_2 emissions of 4.0 Tg CO_2 Eq. (3.4 percent) in 1990 and a decrease of 1.9 Tg CO_2 Eq. (1.7 percent) in 1998. The new civil marine bunker fuel data accounted for almost all of the decrease in CO_2 emissions for 1990. Methane emissions have decreased by less than 0.1 Tg CO_2 Eq. (1.9 percent) in 1990 and less than 0.1 Tg CO_2 Eq. (2.5 percent) in 1998. Nitrous oxide emissions have decreased by less than 0.1 Tg CO_2 Eq. (3.0 percent) in 1990 and less than 0.1 Tg CO_2 Eq. (1.9 percent) in 1998.
- In the Limestone and Dolomite Use section of the Industrial Processes chapter, the activity data used to calculate CO_2 emissions for have been revised to incorporate published 1994 limestone and dolomite consumption (USGS 1995). Previously, limestone and dolomite consumption for 1994 was interpolated using 1993 and 1995 data. Additionally, estimates of the amount of limestone used in glassmaking have been revised for 1996 through 1998. In previous inventories, limestone used in glass making for 1996 through 1998 was assumed to account for the same proportion of total crushed stone consumption as in 1995. However, the USGS published new data (USGS 1999) for 1998 limestone consumption. Now, limestone consumed for glass making in 1996 and 1997 is interpolated, using both the 1995 and 1998 data, and the 1998 data have been updated. Finally, the amount of limestone consumed in 1998 for flue gas desulfurization has been updated to reflect new data (EIA 1999b). These updates resulted in a decrease in annual CO_2 emissions from limestone and dolomite use in 1994 and 1996 through 1998. On average, emissions decreased by 0.4 Tg CO_2 Eq. (2.2 percent).
- In the Nitric Acid Production section of the Industrial Processes chapter, 1998 production data were revised using data from Chemical and Engineering News (C&EN 2000). The revision resulted in a decrease of 0.2 Tg CO_2 Eq. (1.0 percent) in annual nitrous oxide emissions from nitric acid production in 1998.
- In the Substitution of Ozone Depleting Substances section of the Industrial Processes chapter, a review of the current chemical substitution trends, together with input from industry representatives, resulted in updated assumptions for the Vintaging Model, particularly in the precision cleaning solvents, stationary refrigeration, and fire extinguishing sectors. These revisions resulted in an average decrease of 2.1 Tg CO_2 Eq. (19 percent) in HFC, PFC, and SF_6 emissions from substitution of ozone depleting substances for 1994 through 1998.
- In the Aluminum Production section of the Industrial Processes chapter, the smelter-specific emission factors used for estimating PFC emissions from aluminum production were revised to reflect recently reported data concerning smelter operating parameters and smelter emission measurements. These data were provided by the EPA's Climate Protection Division in cooperation with participants in the Voluntary Aluminum Industrial Partnership (VAIP) program. The revisions resulted in an average decrease of 0.2 Tg CO_2 Eq. (4.0 percent) in PFC emissions from aluminum production for 1990 through 1998.

- In the Manure Management section of the Agriculture chapter, two major data revisions occurred. Manure management system data were revised and updated for the entire time series based on data that has been gathered by various sources. These sources include EPA's Office of Water (ERG 2000, UEP 1999), USDA's Animal and Plant Health Inspection Service (USDA 1996b, 1998b, 2000d, 2000e), as well as personal communications with USDA and other experts (Deal 2000, Johnson 2000, Miller 2000, Stettler 2000, Sweeten 2000, Wright 2000). Contacts at Cornell University provided survey data on dairy manure management practices in New York (Poe et al., 1999). The revisions made to the manure management system data account for changes that have occurred in the industry, including more dairies moving away from daily spread systems and installing on-site manure storage systems and layer operations moving from flush systems to high rise housing. The revised data also account for dairies, beef feedlots, swine, and poultry operations handling portions of their manure as a dry waste, either as separated solids or manure collected from scrape systems. In particular, the new data revised the previous assumptions of the number of dairy cattle housed on pasture, range, or paddock, and the amount of manure managed in daily spread systems. Previously, general assumptions had been made that all large dairies and swine operations handle their manure in a liquid system, and all dairies with less than 100 head and swine operations with less than 200 head were managed in pasture, range, or paddock systems. These revised data result in lower CH_4 emissions and higher N_2O emissions.

  Secondly, Census of Agriculture data, which are used to determine the distribution of animals by farm size, were updated for 1992 and 1997. These distributions were then combined with manure management system data to determine State-specific weighted emission factors. The revised data, made available to the public in June 1999, revised the swine farm distribution, which resulted in a decrease in CH_4 emissions, and an increase in N_2O emissions.

  These data changes, together with the methodological changes described below, resulted in annual CH_4 emission estimates from manure management decreasing by an average of 38.3 Tg CO_2 Eq. (56 percent). Additionally, average annual N_2O emission estimates increased by 3.1 Tg CO_2 Eq. (23 percent), due to significant increases in the dairy estimates.
- The estimates of nitrous oxide (N_2O) emissions from agricultural soil management have been updated for a variety of reasons, as described below: Two changes were made to the commercial fertilizer statistics. First, the fertilizer consumption data for 1998 were updated based on revised values published by the Association of American Plant Food Control Officials (AAPFCO 1999). The updated data were less than 1 percent lower than the original data. Second, the nitrogen content of commercial organic fertilizers (4.1 percent in the previous Inventory) was revised to reflect the annual weighted average nitrogen contents published in annual reports of commercial fertilizer statistics (TVA 1991-1994, AAPFCO 1995-1999). These new nitrogen contents varied from 2.3 to 3.9 percent (by mass).

  The annual estimates of livestock manure production were refined through personal communications with livestock experts (Anderson 2000, Deal 2000, Johnson 2000, Lange 2000, Miller 2000, Milton 2000, Safley 2000, Stettler 2000, Sweeten 2000, and Wright 2000). These refinements resulted in a decrease of about 30 percent in the estimates of manure nitrogen applied to soils, a decrease of about 13 percent in the estimates of manure deposited by pasture, range, and paddock animals, and a decrease of about 20 percent in total livestock manure. The fraction of poultry manure assumed to be used as a livestock feed supplement was reduced from 10 percent to 4.2 percent (Carpenter 1992).

  In the calculations of both nitrogen-fixing crop production and crop residue application, the 1998 crop production data for small grains and beans and pulses were changed based upon updated values from USDA (2000b). The updated data for all crops except

peanuts were lower than the USDA estimates used in the previous Inventory; the updated production statistics for peanuts were higher. All changes were less than 1 percent of the original data.

In the calculations of nitrogen-fixing crop production, the crop production data for forage legumes (i.e., alfalfa, red clover, white clover, birdsfoot trefoil, arrowleaf clover, crimson clover, and hairy vetch) were revised to include more detailed crop information, especially about biomass densities and grass/legume mixtures. Hairy vetch was dropped from the calculations because the data used in the previous Inventory were found to be too uncertain. These revisions resulted in a 6 percent decrease in the annual total forage legume production estimates.

The calculation of crop residue applications was revised in several ways. First, the following grains were included in the calculations, in addition to those considered previously: rice, barley, sorghum, oats, rye, and millet. Second, instead of assuming that 100 percent of the residue was left on the field, it was assumed that 90 percent of the residues of all crop types, except rice, were left on the field. For rice residue, it was assumed that all of the unburned residue was left on the field. Third, the conversion factors used in calculating the amount of crop residue applied to soils were revised to more recent, and in many cases, U.S.-based, data. New values for residue dry matter content and residue nitrogen content for wheat, rice, corn, and barley were obtained from Turn et al. (1997), and new values for residue dry matter content and residue nitrogen content for peanuts, sorghum, oats, and rye were obtained from a computer model at Cornell University's Animal Science Department—the Cornell Net Carbohydrate and Protein System (Ketzis 1999). The new values for residue dry matter content and residue nitrogen content for millet, and residue dry matter content for soybeans, were obtained from Strehler and Stützle (1987). The new value for residue nitrogen content for soybeans was obtained from Barnard and Kristoferson (1985). Together, these changes resulted in a 2 to 3 percent decrease in the total annual crop residue nitrogen application estimates.

These revisions, together with the methodological modification described below, resulted in an average decrease of 8.1 Tg CO_2 Eq. (2.8 percent) in estimated annual N_2O emissions from agricultural soil management for 1990 through 1998.

- The estimates of emissions from agricultural residue burning include three changes, as described below:

— Revised USDA crop production data for 1998 from USDA (2000b) have been incorporated. For all crops except sugarcane and peanuts, production estimates were lower than previously reported; the updated production statistics for sugarcane and peanuts were higher. All changes were less than 1 percent of the original estimate.

— Data on the percentage of rice burned in California were updated as a result of conversations with an air pollution specialist with the California Air Resources Board (Najita 2000). More accurate estimates of rice acreage burned in Sacramento Valley were obtained from data collected by the Air Resources Board. These estimates are about 75 to 130 percent higher than the estimates used in the previous Inventory.

— The crop conversion factors, which served as key assumptions for estimating emissions, were revised in this report to reflect data from recent, U.S.-based sources. Updated values for dry matter content, carbon content, and nitrogen content of wheat, rice, corn, and barley were obtained from Turn et al. (1997), and revised values for dry matter content, carbon content, and nitrogen content of peanuts were obtained from a computer model at Cornell University's Animal Science Department—the Cornell Net Carbohydrate and Protein System (Ketzis 1999).

— These revisions, in combination with the methodological revision described below, resulted in an average decrease in agricultural residue burning CH_4 emissions of 0.1 Tg CO_2 Eq. (14 percent), and an average increase in N_2O emissions of less than 0.1 Tg CO_2 Eq. (4.9 percent), for 1990 through 1998.

- In the Land-Use Change and Forestry chapter, the following changes were made to the Forests, Agricultural Soils, and Landfilled Yard Trimmings sections:
  - In the Forests section of the Land-Use Change and Forestry chapter, new data from a U.S. forest survey for 1997 (Smith and Sheffield 2000) were utilized. These 1997 data were used to estimate 1997 carbon stocks for forests and harvested wood, which were combined with the 1992 and 2000 carbon stock estimates to derive carbon flux estimates for intervening years. The flux estimates for 1993 through 1998 in last year's Inventory were derived using a 1992 stock and a projected stock for 2000, since the 1997 forest survey was not yet available.
  - The Agricultural Soils section of the Land-Use Change and Forestry chapter includes two changes, as described below:
  - New data from a preliminary version of USDA's 1997 National Resources Inventory (NRI) (USDA 2000a) were used to derive mineral and organic soil carbon flux estimates for 1993 through 1999. The previous Inventory included only a partial time series of agricultural soil carbon flux estimates, and these estimates were not included in the total net flux estimates presented in the chapter because USDA's 1997 NRI had not yet been completed. This Inventory includes a complete time series of agricultural soil carbon flux estimates, and these estimates are included in the total net flux estimates for land use, land-use change, and forestry.

    The carbon dioxide emission estimates for liming were also changed. The input data for these calculations were revised based on the latest updates from publications of the Bureau of Mines and the U.S. Geological Survey.
  - In the Landfilled Yard Trimmings section of the Land-Use Change and Forestry chapter, the 1998 estimate for yard trimmings disposed in landfills was revised using new data found in EPA (1999). Previously, the 1998 value had been projected.

    These changes, combined with the methodological changes described below, resulted in an average decrease of 125.5 Tg CO_2 Eq. (11.8 percent) in annual carbon sequestration from land-use change and forestry for 1990 through 1992, and an average increase of 233.2 Tg CO_2 Eq. (29.4 percent) in annual carbon sequestration from land-use change and forestry for 1993 through 1998.
- In the Human Sewage section of the Waste chapter, revisions have been made to U.S. Census Bureau population data (2000). Additionally, this report reflects an updated 1998 per capita protein consumption estimate published by the Food and Agriculture Organization (FAO 2000). These revisions resulted in an average increase of 0.1 Tg CO_2 Eq. (1.4 percent) in annual N_2O emissions from human sewage, from 1990 through 1998.
- In the Wastewater Treatment section of the Waste chapter, revisions have been made to national population data for 1990 through 1998 that were supplied by the U.S. Census Bureau (2000). This change, combined with the methodological changes described below, resulted in an average increase of 8.4 Tg CO_2 Eq. (255 percent) in annual CH_4 emissions from wastewater treatment.

Methodological Changes

Carbon Dioxide Emissions from Fossil Fuel Combustion [and] Carbon Stored in Products from Non-Energy Uses of Fossil Fuels

The carbon storage factors used to estimate the carbon stored by the non-energy use of asphalt and road oil, liquefied petroleum gases (LPG), petrochemical feedstocks, pentanes plus, natural gas for other uses (i.e., not used for fertilizers), and lubricants were revised. The role of carbon storage in estimating emissions from the combustion of fossil fuels was explained in previous inventories only in Step 3 in the Methodology for the Carbon

Dioxide Emissions from Fossil Fuel Combustion section of the Energy chapter. For this inventory, the complete list of storage factors, the methods and data used to derive the factors, and the uncertainty involved with their estimation are discussed in a new source category section of the Energy chapter entitled, "Carbon Stored in Products from Non-Energy Uses of Fossil Fuels."

The storage factor revisions were made by examining the lifecycle of the various fuel products. The storage factor for asphalt and road oil remained 100 percent; LPG and pentanes plus were raised to 91 from 80 percent; naphtha petrochemical feedstocks were raised to 91 from 75 percent; other oil feedstocks were raised to 91 from 50 percent; natural gas for other uses was lowered to 91 percent from 100 percent; and lubricants were lowered to 9 percent from 50 percent. Details of the storage factor revisions can be found in Annex B, which has been added to document this new storage factor methodology.

Updated storage factors were developed for fuels according to the following three criteria:

- *Relative size of non-energy fuel consumption.* Nearly two-thirds of the carbon consumed for non-energy uses come from LPG (26 percent), petrochemical feedstocks (19 percent), and asphalt and road oil (19 percent). Combined, the fuels that have been selected represent approximately 305 Tg CO_2 Eq., nearly 64 percent of the total consumed for non-energy uses in 1999.
- *Ability to identify data for fuel products.* Data gathering is made efficient and the uncertainty is reduced when a fuel's uses are limited (i.e., there are only a few important end uses) or well characterized. Asphalt and road oil is a good example of a limited end use fuel, having only two major uses, asphalt paving and roofing. Lubricants are an example of a well-characterized non-energy use of fossil fuel—by virtue of analyses conducted to support rulemakings on used oils, the EPA maintains some data on their fate.
- *Uncertainty in previously used storage factor.* The previous storage factors for certain fuel types or products, and the assumptions upon which they are based, are not expected to be significantly altered through additional research. For example, special naphthas—a generic fuel category which covers highly purified organic compounds, usually containing 4 to 12 carbon atoms—are almost entirely used as solvents. Due to their volatility, they are generally emitted during use and are subsequently photo-oxidized to CO_2 in the atmosphere. Similarly, natural gas used in fertilizer is consumed for ammonia production, and nearly all the carbon is oxidized. The petrochemical feedstocks, on the other hand, lead to many products via a myriad of reaction pathways. In this case, the uncertainty in the storage factor could be reduced significantly by investigating the fuel's processing losses and end uses.

Overall, the storage factor revisions increased the carbon stored from non-energy uses of fossil fuels by an average of 26.9 Tg CO_2 Eq. for 1990 through 1998. These methodological changes, combined with the data changes described above, resulted in an average increase of 6.4 Tg CO_2 Eq. (0.1 percent) of CO_2 annual emissions from fossil fuel combustion for 1990 through 1998.

Mobile Combustion (excluding CO_2)

Annual vehicle mileage accumulation by vehicle age, provided by EPA (2000a), has been incorporated for this report. Previously, only the age distribution of highway vehicle registrations was accounted for when allocating vehicle miles traveled (VMT) to different model years. This change accounts for the fact that newer vehicles are generally driven more than older vehicles. This methodological change, combined with the data changes described above, resulted in an average decrease of 0.4 Tg CO_2 Eq. (7.1 percent) in annual CH_4 emissions from mobile combustion for 1990 through 1998. Average N_2O emissions increased by 3.0 Tg CO_2 Eq. (5.2 percent) annually for 1990 through 1998.

Natural Gas Systems

In the Natural Gas Systems section of the Energy chapter, a new source was added into the estimation of emissions from natural gas production for 1990 through 1999. Coalbed methane wells draw natural gas from deep deposits of coal, and in the course of producing gas, these wells can also produce large amounts of water, which has methane in solution. When the water reaches the surface, the dissolved methane volatilizes. Estimates of these emissions are small, and add approximately 0.15 Tg CO_2 Eq. per year to the total. This change, combined with the data changes mentioned above, resulted in an average decrease of 0.6 Tg CO_2 Eq. (0.5 percent) in annual CH_4 emissions from natural gas systems from 1990 through 1998.

Lime Manufacture

The method for estimating CO_2 emissions from lime manufacture was updated to adhere to IPCC Good Practice Guidance (IPCC 2000). Previously, gross emissions were calculated by multiplying total lime production by an emission factor of 0.73 metric ton CO_2/metric ton of lime. This emission factor was the product of the average CaO/CaO•MgO content of lime, 93 percent, and the stoichiometric ratio of CO_2 to CaO (0.785 metric ton CO_2/metric ton CaO). In this report, lime production was split into high-calcium lime and dolomitic lime, and the emission factors (0.75 and 0.86 metric ton CO_2/metric ton lime, respectively) were updated. Additionally, corrections were made for the amount of hydrated lime produced. These methodological revisions led to an average increase of 0.2 Tg CO_2 Eq. (1.6 percent) in annual CO_2 emissions from lime manufacture for 1990 through 1998.

Semiconductor Manufacturing

The estimates presented in the Semiconductor Manufacturing section of the Industrial Processes chapter in previous Inventories were estimated based on gas sales data from 1994, emission factors for the most commonly used gases, and projections—both backward and forward—regarding the growth of semiconductor sales and the effectiveness of emission reduction efforts. The methodology has been updated to use production data for 1990 through 1994, and reported data from semiconductor manufacturers for other years. These changes resulted in an average decrease of 0.1 Tg CO_2 Eq. (5.0 percent) in annual HFC, PFC, and SF_6 emissions from semiconductor manufacturing for 1990 through 1998.

Magnesium Production and Processing

Emission estimates for the magnesium production and processing industry have been revised to incorporate information provided by EPA's SF_6 Emission Reduction Partnership for the Magnesium Industry. These revisions resulted in an average decrease of 3.6 Tg CO_2 Eq. (37 percent) in annual SF_6 emissions from magnesium production and processing from 1990 through 1998.

Enteric Fermentation

Four major changes to the methodology used in estimating enteric fermentation emissions from cattle were completed in this report: 1) an enhanced population characterization method (i.e., IPCC Tier 2) was adopted for cattle only; 2) diet characterizations were expanded to apply to development of emission factors for the new population modeling structure; 3) certain DE and Y_m values were evaluated using a physiological model; and 4) new equations were implemented based on IPCC Good Practice Guidance (IPCC 2000).

For cattle, all historical emission estimates have been updated using the IPCC Good Practice Guidance Tier 2 approach. These methods for estimating methane emissions from enteric fermentation resulted in increased levels of detail, such as definitions of livestock sub-categories, livestock populations by sub-category, and feed intake estimates for the typical animal in each sub-category. Cattle populations were categorized in much more depth through the modeling of the populations by month. Factors such as weight gain, birth, pregnancy, feedlot placements, and slaughter were tracked to characterize the U.S. cattle population in greater detail than in previous inventories, in which only end of year population data were used.

Diets of beef, dairy, and feedlot animals were updated from the values presented in EPA (1993) by research-

ing regional diets throughout the United States. A ruminant digestion model (Donovan and Baldwin 1999) and expert opinion (Johnson 1999) were used to derive DE and Y_m values for the selected animal categories using the results of the diet research. These estimates were used to develop new emission factors for all animal categories studied, with the exception of bulls.

The net energy and methane emission equations presented in IPCC (2000) were incorporated into a computer model that contains the population characterization to estimate emissions for each of the selected cattle population categories, both regionally and temporally. In previous Inventories, national emission factors recommended by IPCC/UNEP/OECD/IEA (1997) were used with static information relevant to broader classifications of the cattle industry to estimate total emissions. These methodological changes resulted in an average increase in annual CH_4 emissions from enteric fermentation of 7.3 Tg CO_2 Eq. (5.9 percent) from 1990 through 1998.

Manure Management

Several changes have been incorporated into the manure management emission estimates that affect estimates for all years. The major changes affecting the estimates are described below:

- *Swine Population Characterization Revisions.* Historically, swine population was broken into two groups: breeding swine (i.e., gestating sows, farrowing sows, and boars) and all market swine. For this report, the entire time series has been revised to account for different weight groups of market swine. Specifically, the market swine population was broken into four groups: swine less than 60 pounds (<27 kg), swine 60 to 119 pounds (27 to 54 kg), swine 120 to 179 pounds (54 to 81kg), and swine greater than 180 pounds (>82 kg). The population estimates for each size group were based on quarterly and annual population data available from USDA's National Agricultural Statistics Service (USDA 1998a, 2000c). The representative weight for each size group was set at the mid-point of the weight range, with the exception of the swine less than 60 pounds and swine greater than 180 pounds. The representative weight for these two size groups were based on expert judgment (Safley 2000).
- *Waste Characteristics Data Revisions.* Other animal waste characteristics were also revised to match data found in USDA's Agricultural Waste Management Field Handbook (USDA 1996a), in order to distinguish waste characteristics between various animal subgroups. For example, distinctions were made in the amount of volatile solids and nitrogen excreted by market swine in various stages of growth, beef cattle that are grazed versus beef cattle on high energy feed, and between lactating and dry dairy cows. The data source for waste characteristics for all livestock except sheep, goats, and horses was changed to the Agricultural Waste Management Field Handbook (USDA 1996a). The volatile solids and nitrogen excretion data for breeding swine are a combination of the types of animals that make up this animal group, namely gestating and farrowing swine and boars. It was assumed that a group of breeding swine is typically broken out as 80 percent gestating sows, 15 percent farrowing swine, and 5 percent boars (Safley 2000). In addition, B_o values used in previous estimates were reviewed and updated for dairy and beef cattle, swine, and poultry.

  Most significantly, volatile solids and nitrogen excretion data for immature swine were accessed from USDA's Agricultural Waste Management Field Handbook (USDA 1996a), and coupled with revised animal masses for the new population groups. Previously, the methodology for estimating these emissions assumed that all market swine generate volatile solids and nitrogen at a rate equal to a 255-pound (116 kg) swine. That methodology overestimated the amount of volatile solids and nitrogen generated, as well as the subsequent emissions of methane and nitrous oxide. These changes resulted in a roughly 70 percent drop in both volatile solids production and nitrogen excretion for swine operations.
- *Dairy Cow Volatile Solids Production Revisions.* The method for calculating volatile solids production from dairy cows was revised to better address

the relationship between milk production and volatile solids production. Cows that produce more milk per year also produce more volatile solids in their manure due to their increased feed. Data from the Agriculture Waste Management Field Handbook were used to determine the mathematical relationship between volatile solids production and milk production for a 1,400-pound dairy cow (USDA 1996a). Annual milk production data, published by USDA's National Agricultural Statistics Service (USDA 2000f), was accessed for each State and for each year 1990 through 1999. State-specific volatile solids production rates were then calculated and used instead of a national volatile solids constant.

- *Methane Conversion Factor (MCF) Revisions.* Historically, for the calculation of methane emissions, default MCFs from IPCC were used for all manure management systems. However, the IPCC Good Practice report (IPCC 2000) now provides a range of 0 to 100 percent as the MCF for anaerobic lagoons. Rather than choosing an MCF for all U.S. systems based solely on judgement, a methodology was developed to reflect the range in performance that is achieved by lagoon systems, and other liquid-based systems. Therefore, the entire time series was revised to incorporate a new method of calculating MCFs for liquid/slurry, deep pit, and anaerobic lagoon systems. The new calculation method is based on the mean ambient temperature of the location of the manure management system (Safley and Westerman 1990), represented by the State and the counties in which specific animal populations reside (USDA 1999). The calculation of the anaerobic lagoon MCF includes an additional approach to account for the timing and length of storage exhibited by these systems, which allows the organic matter to continue to break down over time, increasing the potential for methane production. This approach assesses the production of methane on a monthly basis, and accounts for residual volatile solids that are retained in the lagoon from previous months. In addition, the calculation includes an adjustment for the effect of management and design practices. This factor accounts for other mechanisms by which volatile solids are removed from the management system prior to conversion to methane, such as solids being removed from the lagoon for application to cropland. This factor, equal to 0.8, has been estimated using currently available methane measurement data from anaerobic lagoon systems in the United States (Safley and Westerman 1998 and 1992; Martin 2000). This methodology can be refined over time as new measurements and temperature data are gathered to reflect lagoon performance in the United States.

Nationally, the CH_4 emission estimates for the entire time series dropped between 50 to 60 percent. Swine estimates dropped most significantly (62 percent to 72 percent), followed by poultry (52 percent to 60 percent), dairy (38 percent to 44 percent), and beef (25 percent to 31 percent). Sheep emission estimates dropped by 19 percent across all years of the inventory due to a correction in animal weight and the related correction to volatile solids production. The combined effect of these changes, together with the data changes described above, resulted in a decrease in CH_4 emission estimates from manure management of 38.3 Tg CO_2 Eq. (56 percent) on average from 1990 through 1998.

The N_2O emission estimates for the entire time series increased between 17 to 27 percent primarily due to significant increases in the dairy estimates. Swine N_2O estimates for the time series dropped by 40 percent, while beef dropped about 5 percent. The combined effect of these changes, together with the data changes described above, resulted in an increase in the average annual N_2O emission estimates from manure management of 3.1 Tg CO_2 Eq. (23 percent).

Rice Cultivation

There was a calculation error in the rice cultivation spreadsheets used in the previous Inventory. This has been identified and corrected, resulting in a slightly lower emission estimate for 1996, and higher emission estimates for 1992 through 1995 and 1997 and 1998. This correction

resulted in an average increase of 0.1 Tg CO_2 Eq. (0.9 percent) in annual methane emissions from rice cultivation for 1992 through 1998.

Agricultural Soil Management

The estimates of nitrous oxide (N_2O) emissions from the pasture, range, and paddock manure sub-source were derived by applying the emission factor to total pasture, range, and paddock manure nitrogen, rather than just the unvolatilized portion. In the previous Inventory, the emission factor was applied to the unvolatilized portion of pasture, range, and paddock manure.

This methodological change, in combination with the revisions to historical data, resulted in an average decrease of 8.1 Tg CO_2 Eq. (2.8 percent) in estimated annual N_2O emissions from agricultural soil management for 1990 through 1998.

Agricultural Residue Burning

The emission factor for methane from agricultural residue burning was revised to reflect the default value in the *Revised 1996 IPCC Guidelines* (IPCC/UNEP/OECD/IEA 1997). The default emission factor from the previous version of the IPCC Guidelines was used in the previous Inventory. This methodological change, in combination with the revisions to historical data described above, resulted in an average decrease in agricultural residue burning CH_4 emissions of 0.1 Tg CO_2 Eq. (14 percent), and an average increase in N_2O emissions of less than 0.1 Tg CO_2 Eq. (4.9 percent), for 1990 through 1998.

Land-Use Change and Forestry

The Land-Use Change and Forestry chapter comprises three sections: 1) Forests; 2) Agricultural Soils; and 3) Landfilled Yard Trimmings. The methodologies used in the first two sections have changed relative to the previous Inventory. The changes to each section are described below.

- *Forests*. First, the treatment of specific portions of the forest land base (i.e., Timberland, Reserved Forest Land, and Other Forest Land[27]) has changed. Previously, carbon stock and flux estimates for private Timberlands were estimated using the FORCARB model and associated forest sector models (Birdsey and Heath 1995). Carbon estimates for all other forestlands (i.e., public Timberlands, all Reserved Forest Land, and all Other Forest Land) were estimated by multiplying regional forest statistics resource data (e.g., Powell et al. 1993) by average regional carbon conversion factors obtained from information in the FORCARB model. In this Inventory, carbon estimates for both the private and public Timberlands are derived from the FORCARB modeling framework, i.e., using the method that was used for only private Timberlands previously. Carbon estimates for all Reserved Forest Land and Other Forest Land, regardless of ownership, are still calculated by multiplying regional forest statistics data by average regional carbon conversion factors. However, forest statistics data are available for 1997, and carbon conversion factors are updated on these lands. In this Inventory, Reserved Forests are assumed to contain the same carbon stock per acre as Timberlands of the same forest type, region, and owner group. For Other Forest Land, carbon stocks per acre were calculated for the lowest productivity class of Timberland, and multiplied by 80 percent to represent carbon stocks of these lower productivity lands.

  Second, a preliminary model to estimate net logging residue flux was employed. Logging residues were not included in the previous Inventory.

  And lastly, calculations for products and landfills are now based on estimates of the model constructed by Skog and Nicholson (1998). This model has a similar structure to the model by Heath et al. (1996) that was previously used; however, annual estimates are produced based on wood product surveys. Net storage of landfilled carbon is substantially greater in this model, based on work that indicates that current landfill management practices result in low decay rates.

[27] Timberland is unreserved forest land that is producing or is capable of producing crops of industrial wood. It is the most productive type of forest land, growing at a rate of 20 cubic feet per acre per year or more. Reserved Forest Land is forest land withdrawn from timber use by statute or regulation. Other Forest Land is unreserved forest land, growing at a rate less than 20 cubic feet per acre per year.

- *Agricultural soils.* Three changes have been made to the methodologies used to estimate mineral and organic soil carbon flux. First, last year's Inventory included the total land base included in USDA's soil survey database. The data included in this year's Inventory only include land areas that are classified as cropland or grazing land in 1987, 1992, and/or 1997. Second, in estimating carbon stock changes for last year's Inventory, input data were aggregated prior to estimating stock changes (Eve et al. 2001). This resulted in an underestimate of stock changes for some land areas. For this year's Inventory, stock changes were estimated for each data point, and then aggregated (Eve et al. 2000), resulting in a more precise estimate of net flux. Third, an error in the computer code used in last year's Inventory was identified and corrected.

These changes, combined with the revisions to historical data, resulted in an average decrease of 125.5 Tg CO_2 Eq. (11.8 percent) in annual carbon sequestration from land-use change and forestry for 1990 through 1992, and an average increase of 233.2 Tg CO_2 Eq. (29.4 percent) in annual carbon sequestration from land-use change and forestry for 1993 through 1998.

Landfills

The methodology used to estimate recovered landfill gas has been updated in two ways. First, methane recovered for landfill gas-to-energy (LFGTE) electricity projects was estimated based on reported capacity (i.e., megawatts) rather than reported landfill gas flow. Although the data on electricity capacity are generally considered more reliable than the landfill flow data, capacity data tend to be underestimated. The main reason for this underestimation is the tendency of landfill owners/operators to undersize the units to ensure a sufficient and steady flow of gas to support the unit. Second, in order to avoid double counting, the estimate of methane emissions avoided due to flaring was reduced to adjust for LFGTE projects for which a vendor-specific flare could not be identified. These steps resulted in a downward revision of landfill gas recovered. Also, this report reflects flare data from an additional two vendors, resulting in the evaluation of 487 flares, as compared to 190 for the previous Inventory. Finally, this report includes data on 36 additional LFGTE projects. These methodological changes resulted in an average increase in annual methane emissions from landfills of 1.5 Tg CO_2 Eq. (0.7 percent). This increase is primarily due to a reduction in the estimate of methane emissions avoided at LFGTE projects, which is mainly a result of the use of a more conservative approach for estimating methane avoided.

Waste Combustion

The Waste Combustion section of the Waste chapter has been revised substantially. Formerly, only CO_2 emissions from the combustion of plastics and N_2O emissions from municipal solid waste were included. Carbon dioxide from the combustion of tires, synthetic rubber, synthetic fabrics, and hazardous waste have been added. These updates have increased the average emissions from waste combustion by 10.5 Tg CO_2 Eq. (91.5 percent) for 1990 through 1998.

Wastewater Treatment

The value for wastewater biological oxygen demand (BOD) produced per capita has been revised from 0.05 to 0.065 (kg/capita/day). The 0.05 value was referenced from IPCC/UNEP/OECD/IEA (1997). The revised value of 0.065 is the value given for the United States in EPA (1997). The IPCC Good Practice Guidance (IPCC 2000) has a default value of 0.06 for this parameter; however, that value represents an average for all countries. The wastewater BOD is slightly higher in the United States due to its use of garbage disposals, as stated in EPA (1997). Additionally, the emission factor has been changed from 0.22 kg CH_4/kg BOD to 0.6 kg CH_4/kg BOD to reflect the IPCC Good Practice Guidance (IPCC 2000). Additionally, an estimate of emissions from pulp and paper operations has been included for the first time under the wastewater category. These methodological revisions, together with the data changes described above, resulted in an average increase of 8.4 Tg CO_2 Eq. (255 percent) in annual methane emissions.